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Assessment of bioenergy potential on marginal land in China

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ABSTRACT

Bioenergy developed from energy plants will play a more and more important role in future energy supply. Much attention has been paid to energy plants in recent years. As China has fairly limited cultivated land resources, the bioenergy development may mainly rely on the exploitation of marginal land. This study focused on the assessment of marginal land resources and bio-fuel potential in China using newly acquired data and Geographic Information System (GIS) techniques. A multi-factor analysis method was adopted to identify marginal lands for bioenergy development in China, with data of several main types of energy plants on the eco-environmental requirements and natural habits employed. A combined planting zonation strategy was proposed, which was targeted for five species of energy plants including Helianthus tuberous L., Pistacia chinensis, Jatropha curcas L., Cassava and Vernicia fordii. The results indicated that total area of marginal land exploitable for development of energy plants on a large scale was about 43.75 million ha. If 10% of this marginal land was fully utilized for growing the energy plants, the production of bio-fuel would be 13.39 million tons.

Contents

1. Introduction

Rapidly increasing energy demand has become a serious challenge both in developed and developing countries. Exploitation of renewable energy and sustainable energy is one of the effective solutions to this problem. Development of renewable energy can not only contribute to the energy supply, but also achieve economic and environmental benefits [1]. Biomass energy is the most abundant and versatile type of renewable energy in the world [2]. More and more attention has been paid to bioenergy developed from energy plants in recent years. For example, Valdez-Vazquez et al. presented the prospects of the crop straw in Mexico [3]; Van

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Table 1
Different results of assessment on the marginal land and bioenergy in China.

Authors/time	Definition of marginal land	Coverage of marginal land	Data source	Marginal land/bio-fuel
Kou et al. [13]	Land may be used for growing energy crops as wasteland and paddy land fallowed in winter	Natural grassland, sparse forestland, shrub land and unused land, winter-fallowed paddy land	Statistical data from the Ministry of Agriculture of China, 2006–2007	34.2 million ha (including 7.4 million ha of winter-fallowed paddy land)/45.42 million ton bio-ethanol
Tian et al. [16]	Used land may be cultivated for growing non-food energy plants	Saline land, barren hills and wasteland	Land use data reported by the Ministry of Land and Resources, China, 2000–2003	7 million ha/22 million ton bio-ethanol
Yan et al. [17]	Used land with poor natural conditions, and may be used for growing energy crops	Shrub land, grassland, saline land, bare land, reed swamp, tidal flat and unused land	Land use data reported by the Ministry of Land and Resources, China, 1996, 2000–2003	24.1 million ha/74.0 million ton bio-ethanol
Tang et al. [8]	Used land with poor natural conditions, and may be used for growing energy crops, as well as land that is marginally located and not usually in use for food crops due to the smallness of size, or unclear ownership	Wasteland, land riser/boundary, road side land, stream side land, house surroundings, land along highways/roads	Literature [17], and field survey data of their own	34.7 million ha/107 million ton bio-ethanol

Hoesen and Letendre conducted an evaluation on the potential of renewable energy in Poultney [4], Vermont; Fiorese and Giorgio adopted a GIS-based approach to evaluate the potential of biomass energy in Northern Italy [5]; Lovett et al. estimated the bioenergy prospects in Miscanthus in England [6]; and Kukk et al. evaluated the suitability of growing energy plants on the barren land in Tartu County in Estonia with GIS techniques [7].

In China, bioenergy developed from energy plants is playing a more and more essential role in the national energy structure. China has set the target that the share of renewable energy in the energy structure shall reach 20% by 2020. In 2008, the total bio-fuel production in China was 1.82 million tons, including 1.46 million tons of bio-ethanol and 0.36 million tons of biodiesel [8]. Based on the national mid- and long-term planning of renewable energy development, bio-fuel developed from non-food plants is expected to be 12 million tons by 2020, including 10 million tons of bio-ethanol and 2 million tons of biodiesel [9]. As China has fairly limited cultivated land resources, it is widely acknowledged that the development of energy plants should not affect food security and environment, therefore, the bioenergy development may mainly rely on the marginal land.

The availability of land to grow energy plants is the primary factor for the bioenergy development. Relevant researches have been conducted on the assessment of reserves of bioenergy from energy plants on a regional scale. These researches include evaluation of marginal land for energy plants in Jiang Xi Province [10], GIS-based assessment of quality of marginal land in Zhangzhou City in South China [11], and study on the plant resources for biodiesel energy growing in the Three Gorge Project region [12]. A nation-wide investigation was conducted from 2007 to 2008 by the Ministry of Agriculture of China. The potential of marginal land that can be used for energy plants and the corresponding bio-fuel production potential have been estimated [13]. Several similar researches could be seen in recent literatures [14–17]. However, the estimation of bioenergy potential in China in the above-mentioned researches varied dramatically, mainly because of the following factors: (1) the different definitions of marginal land; (2) the different species of energy plants selected for evaluation; (3) the different sources of data used (Table 1).

The main objective of this study is to present a comprehensive assessment on the potential of bioenergy from non-food energy plants in China. A reasonable and reliable assessment result should be dependent on two conditions: (1) sufficient and accurate data; (2) assessment approaches based on actual situation [18]. According to these conditions, remote sensing-derived land use data at 1:100,000 scale for the year 2008, accurate environmental data, together with data on the natural habits of energy plants were adopted from existing literatures. A GIS-based approach was employed to identify the spatial distribution of marginal lands for bioenergy development. A comprehensive analysis strategy was also applied for the region where more than one species of energy plants were suitable grow. In order to ensure the security of food supply and eco-environmental requirements, 5 major species of non-food energy plants were selected for estimation of energy (bio-fuel) potential in these marginal lands.

This study consisted of four chapters. Chapter 2 described the data acquisition and methodology for evaluation of bioenergy potential from energy plants; Chapter 3 introduced the results of assessment. Conclusions were drawn in Chapter 4.

2. Methodology

Evaluation of bioenergy potential based on the marginal land was conducted as following steps:

Step 1: Identification of marginal land. Marginal land which was suitable for growing the energy plants was identified from 25 sub-types of land use dataset according to a set of criteria. The outputs of this step were total amount and spatial distribution of marginal land in China.

Step 2: Planting zonation of main species of energy plants on the marginal land. Energy plants that were suitable for bio-fuel development were identified. Then, the most suitable place for the growth of each energy plant was determined based on their biological characteristics, environmental requirements, developmental status, type of farming system and natural geographic conditions.

Step 3: Evaluation on the bioenergy potential of energy plants in China conducted according to availability of marginal land, level of exploitation and utilization and species of energy plants.

2.1. Identification of marginal land for energy plants

The Ministry of Agriculture of China has presented the criteria for assessment on the marginal land [13]. In this study, this set of criteria was adopted and revised according to the qualitative analysis on the energy plants in different parts of China, together with suggestions of experts on local planting of energy plants, land resources and ecology, etc. An evaluation criteria system was set up containing 8 factors of 4 categories in total (Table 2).

According to the evaluation criteria system mentioned above, the input data for this study included land-use data, terrain data (including elevation and slope), meteorological data

Table 2
Main factors and parameters for the identification of marginal land.

Factors	Parameters	Scale	Data sources
1. Land-use	1.1 Land use type	1:100,000	Data Center for Resources and Environmental Sciences (RESDC)
2. Terrain	2.1 Elevation	1:100,000	State Bureau of Surveying and Cartography (SBSC)
	2.2 Slope	1:100,000	SBSC
3. Climate	3.1 Precipitation	–	China Meteorological Administration (CMA)
	3.2 Temperature	–	CMA
4. Soil	4.1 Soil type	1:100,000	RESDC
	4.2 Alkalization	1:100,000	RESDC
	4.3 Effective depth	1:100,000	RESDC

(including precipitation data and air temperature data) and soil data.

2.1.1. Land use

A more precise assessment of marginal land is essential for the future planning of growing bioenergy plants. Based on the discussion above, marginal land for energy plants in this study refers to the land that has relatively poor natural condition but is able grow energy plants, or land that currently is not used for agricultural production but can grow certain plants. In general, China's marginal land for the development of energy plants includes woodland (shrub land, sparse forest land), grassland and barren land (including shoal/bottomland, saline and alkaline land, and bare land). Development of energy plants in marginal land should not affect local environment and ecology, so that pasturing area, forest and reserves such as natural reserve, water conservation district, should be excluded. Moreover, small patches of marginal lands, like land risers and land boundaries, are also not taken into consideration.

To ensure the accuracy and consistence of data, besides conventional statistical data, land-use data of China at the scale of 1:100,000 for 2008 were used in this study. The dataset was obtained through Landsat^{TM} (Thhematic Mapper) and CBERS-2 (China-Brazil Earth Resources satellite) satellite images and interpreted by experts in the Data Center for Resources and Environmental Sciences (RESDC), Chinese Academy of Sciences [19]. Land-use types falls on six categories and 25 sub-categories and they are listed as follows: (1) cultivated land; (2) woodland; (3) grassland; (4) water; (5) urban and rural settlements; (6) barren land. A set of land data from field surveys was selected to guarantee the accuracy of land-use classification. It is the newest land-use dataset at this scale in China and used as the most fundamental data for identification of marginal land which could be potentially used for the development of sustainable biomass energy.

2.1.2. Terrain

An authorized terrain dataset including elevation and slope at the scale of 1:100,000 was supplied by State Bureau of Surveying and Cartography (SBSC) of China. Slope is an important indicator in marginal land identification. Land with slope over 25° was excluded because water loss and soil erosion occurred easily for this kind of land. Threshold of elevation was determined according to species of energy plants, which would be discussed in Section 2.2.

2.1.3. Climate

Data of precipitation and air temperature, two key factors for plant growth, were presented by China Meteorological Administration (CMA). The water and temperature requirements varied for different species of energy plants. This would also be discussed in Section 2.2.

2.1.4. Soil

Soil quality was determined by several parameters, including soil type, alkalization, and effective soil depth. Nation-wide soil dataset at the scale of 1:100,000, provided by RESDC, was used. Loam soil, clay, sandy loam soil, gault soil were considered as suitable soil for energy plants. Sand, sandy soil and gravel soil were excluded. Seriously alkalized soil and saline soil were also excluded [21]. Threshold of effective soil depth was determined as 30 cm in northern regions (including Huang-Huai-Hai region, Northeast China, Northwest China, Loess Plateau, and Qinghai-Tibetan Plateau), and 20 cm in southern regions (including Southeast China, Sichuan Basin, the middle and lower reaches of Yangzi River, and the Yunnan-Guizhou Plateau) respectively [13].

Before further processing, all of the source data were re-sampled onto a raster dataset with 1000 m spatial resolution. Meanwhile, the data were transformed to the same coordinate system (Albers Equal Area projection system with original longitude 105°E, double standard parallel of 27°N and 45°N, Beijing 1954 geodetic datum and Krassovsky ellipsoid).

2.2. Main energy plants and natural habits

To ensure the security of food supply, the basic principles have to be followed for the future development of bio-fuels in China: non-food plants for fuels and non-farm land for energy plants [1,2,13]. This helps in determining that the energy plants are non-food feedstock which can be planted on the non-farming land. In this study, crops such as sweet sorghum, sweet potato, sugarcane were not discussed.

Energy plants consists of several types: (1) energy plants for bio-ethanol, mainly including plants with high content of saccharide, starch and fiber; (2) energy plants for biodiesel, especially non-food oil plants, etc. China has 1554 species of oil plants, including 154 species with oil content greater than 40% in seeds, and 30 species of shrubs or arbor plants with rich bio-fuel components [20]. However, the species which could be planted on the barren land on a large scale were quite limited. Based on the literature and field survey data, 5 species of energy plants were selected: Helianthus tuberous L., Cassava, and three woody oil plants (Pistacia chinensis, Jatropha curcas L., Vernicia fordii). These species were all mentioned in the 11th Five-Year Plan and have been planted in many experimental areas. This study focused on the availability of the land resources for these plants and bio-fuel potential according to their natural habitats and their potential for cultivation under various environmental conditions [1,2,20,23].

2.2.1. Jerusalem artichoke

Jerusalem artichoke (H. tuberous) is one of the 90 species of plants within the sunflower family. It is a fructose-based energy plant with the highest content of polyfructose (80% of dry tuber). Jerusalem artichoke can be found in diverse habitat. Climate for maximum growth is moderate temperatures (18–26 °C), and optimal soil for plant growth is slightly alkaline with sufficient

Table 3
Eco-environmental requirements of main energy plants in China.

Species	Annual accumulated precipitation (mm)	Annual averaged temperature (°C)	Elevation (m)
Helianthus tuberous L.	>160	Annual accumulated temperature (above 0 °C) > 2000 °C	<3500
Cassava	>600	>18	<2000
Pistacia chinensis	>400	>5.8, annual accumulated temperature (above 10 °C) > 1180 °C	140–3500
Jatropha curcas L.	480–2380	>17	700–1600
Vernicia fordii	750–2200	>17	200–800

moisture. However, it can adapt to cold and arid climates, and can grow in saline and alkaline land. The reported yield of Jerusalem artichoke is 45–90 ton per ha (underground tuber).

2.2.2. Cassava

Cassava (Manihot esculenta) is a woody shrub of the Euphorbiaceae. The tuberous root of cassava is a major source of carbohydrates. It is drought-tolerant, disease-resistant and easy to plant. Cassava is mainly cultivated in sub-tropic regions in Guangxi, Guangdong, Hainan Province in South China. In 2009, the total planting area of cassava was 0.41 million ha in China, with cassava yield of 0.62 million tons [22].

2.2.3. P. chinensis

P. chinensis (Chinese Pistache) is a tall deciduous tree native to central and western China. It can withstand harsh conditions and poor-quality soils, and some species of Pistacia even could tolerate temperatures below −25 °C. A national survey conducted in 2002 indicated that P. chinensis could be found in more than 23 provinces in North, Central and South China, and was mainly distributed on the hill and mountain with the altitude lower than 3500 m.

2.2.4. J. curcas L.

J. curcas is a species of semi-evergreen tree in the spurge family and native to the tropical America. It is now cultivated in tropical and subtropical regions in southern China, especially in Yunnan, Guizhou and Sichuan Province. The plantation area of Jatropha was estimated in 2008 at around 0.15 million ha in these three provinces, accounting for 95% of the total area in China. J. curcas is resistant to a certain degree of aridity. The seeds of J. curcas contain 27–40% oil [6] that can be processed to produce a high-quality bio-diesel fuel.

2.2.5. V. fordii

V. fordii (Tung Tree) is a species of Vernicia in the spurge family, native to southern China, Burma, and northern Vietnam. It is planted in Yangtze River Valley and its southern areas, mainly in Sichuan, Hunan, Hubei and Guizhou Province. Optimal environmental conditions for V. fordii include worm and dank climate, acid or neutral sandy loam soil. The nutlets of Vernicia contain 60–70% oil, and the average yield of oil is about 450–600 kg/ha.

Eco-environmental requirements of those 5 main energy plants in China are listed in Table 3 [1,2,20].

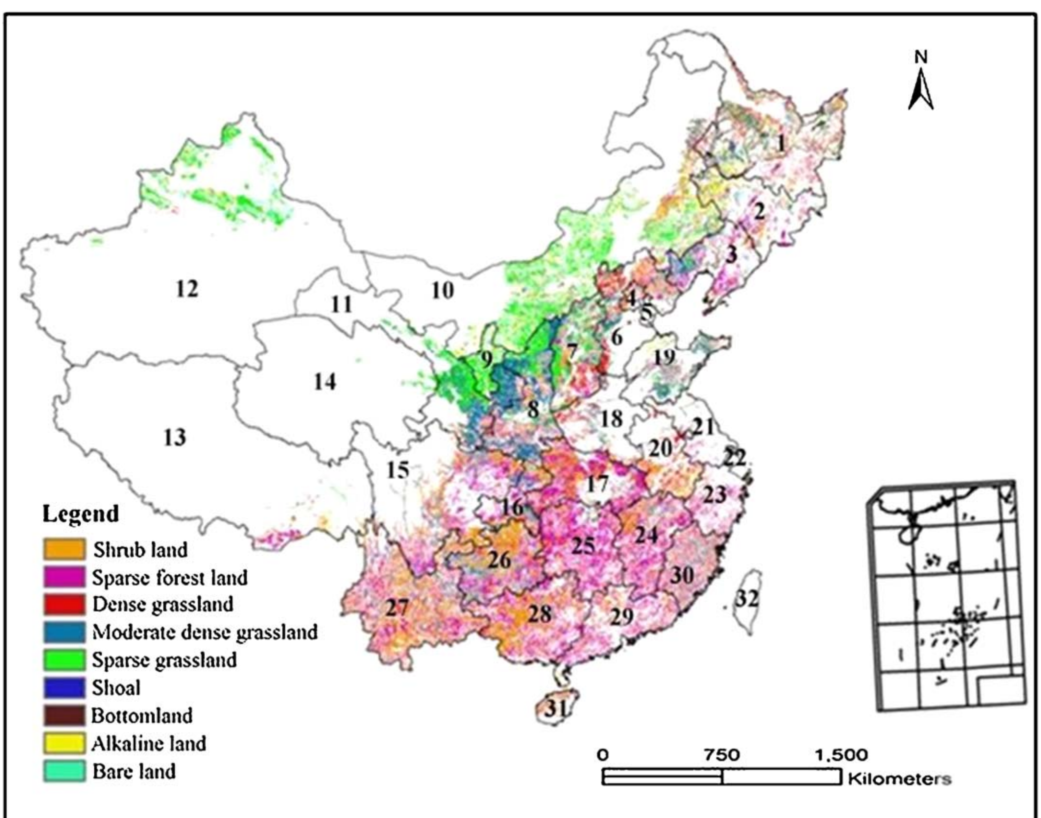


Fig. 1. Spatial distribution of marginal land suitable for energy plants in China. *Note*: The number 1 to 32 stand for different provinces/cities of China: 1, Heilongjiang; 2, Jilin; 3, Liaoning; 4, Beijing; 5, Tianjin; 6, Hebei; 7, Shanxi; 8, Shaanxi; 9, Ningxia; 10, Nei Monggol; 11, Gansu; 12, Xinjiang; 13, Tibet; 14, Qinghai; 15, Sichuan; 16, Chongqing; 17, Hubei; 18, Henan; 19, Shandong; 20, Anhui; 21, Jiangsu; 22, Shanghai; 23, Zhejiang; 24, Jiangxi; 25, Hunan; 26, Guizhou; 27, Yunnan; 28, Guangxi; 29, Guangdong; 30, Fujian; 31, Hainan; 32, Taiwan (lack of data).

Table 4
Composition of marginal land suitable for energy plants in China.

Land use types	Area (million ha)	Percent (%)
Shrub land	36.10	27.70
Sparse forest land	29.52	22.65
Dense grassland	19.04	14.61
Moderate dense grassland	22.48	17.25
Sparse grassland	17.99	13.80
Shoal/bottomland	2.18	1.67
Alkaline land	2.49	1.91
Bare land	0.54	0.41
Total	130.34	100

3. Results and discussion

3.1. Marginal land resources in China

Based on the identification of marginal land (Section 2.1) together with natural habits of major energy plants, the marginal land with potential for planting energy plants was identified for each 1 km × 1 km grid across China. The results are shown in Fig. 1.

The results indicated that the total area of marginal land suitable for energy plants was estimated up to 130.34 million ha (Table 4). Forest land (shrub and sparse forest land) and grassland are two major components of marginal land, accounting for 50.35% and 45.66% of total area respectively. Shoal/bottomland and alkaline land, which account for 1.67% and 1.91% of total area respectively, might also be exploited for the development of energy plants.

The results indicated that marginal land resources were mainly distributed in two areas in China. One of them is Southwest China, including Yunnan, Guizhou, Sichuan Province and Chongqing City (Fig. 2). The area of marginal land in this region is about 38.7 million ha, accounting for 39.1% of the total across China. Due to plenty of water resources and sufficient sunshine, it is one of the most important regions for development of energy plants in China. Another area is Inner Mongolia and Northeast China. The potential of energy plants is considerable for the abundant marginal land resources (accounting for 12.9% of the total area of marginal land across China), with relative low slope and high soil quality. There are quite a few marginal land resources in Shaanxi and Gansu Province in Northwest China, however, it is the arid region with serious soil erosion there, so that eco-environmental security should be placed much emphasis during the planning of growing energy plants in this region.

According to biological characteristics, environmental requirements and natural geographic conditions, the most suitable place for the development of each energy plant was determined using the GIS spatial analysis function. An integrated land-use strategy was also adopted for the region where more than one species were suitable to grow. The results are shown in Fig. 3.

In terms of plant species, the suitable places for Cassava, J. curcas L., and V. fordii mainly distribute in sub-tropic regions in South and Southwest China. H. tuberous L. and P. chinensis have wide and strong adaptability to environmental conditions, such as drought, low temperature, salt and alkali. They might be planted in North and Northwest China. H. tuberous L. may also be planted in the marginal land along Tianshan Mountain in Xinjiang Province, cold area in Northeast China, and even part of places in the south of Tibet Plateau (Fig. 3).

3.2. Bio-fuel potential of energy plants in China

Evaluation of bioenergy potential of energy plants was conducted according to availability of marginal land and yields of main species of energy plants. For the development of energy plants on a large scale, eco-environmental effects should also be considered. For this reason, the shrub, high and moderate coverage grassland were excluded to ensure that the exploitation of marginal land would not affect eco-environmental security. Open forest land was excluded for herbaceous (H. tuberous L.) and woody shrub (Cassava) energy plants in order to achieve maximum ecological benefits. The final results about bio-fuel potential of energy plants in China are then presented in Table 5.

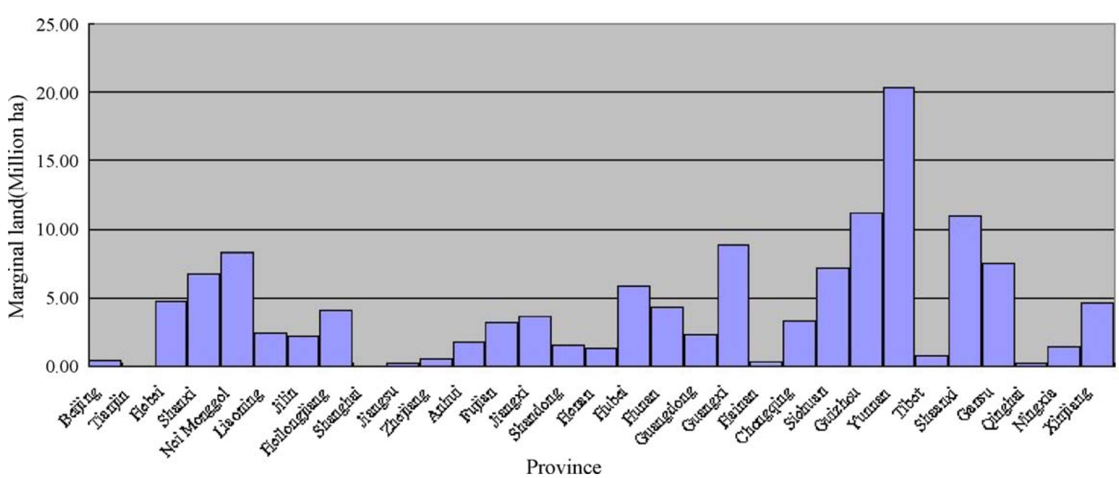


Fig. 2. Histogram of marginal land suitable for energy plants in different provinces in China.

Table 5
Bio-fuel potential of energy plants in China (Area unit: million ha).

	Sparse forest land	Sparse grassland	Shoal/bottomland	Alkaline land	Bare Land	Total area	Biofuel (million ton)
Helianthus tuberous	–	13.63	1.1	2.36	0.51	17.62	52.85
Pistacia chinensis	17.64	4.22	0.93	0.13	0.02	22.94	68.81
Jatropha curcas L.	2.89	0.06	0.07	0	0	3.02	11.33
Cassava	–	0.09	0.08	0	0.01	0.17	0.86
Total	20.53	18	2.18	2.49	0.54	43.75	133.85

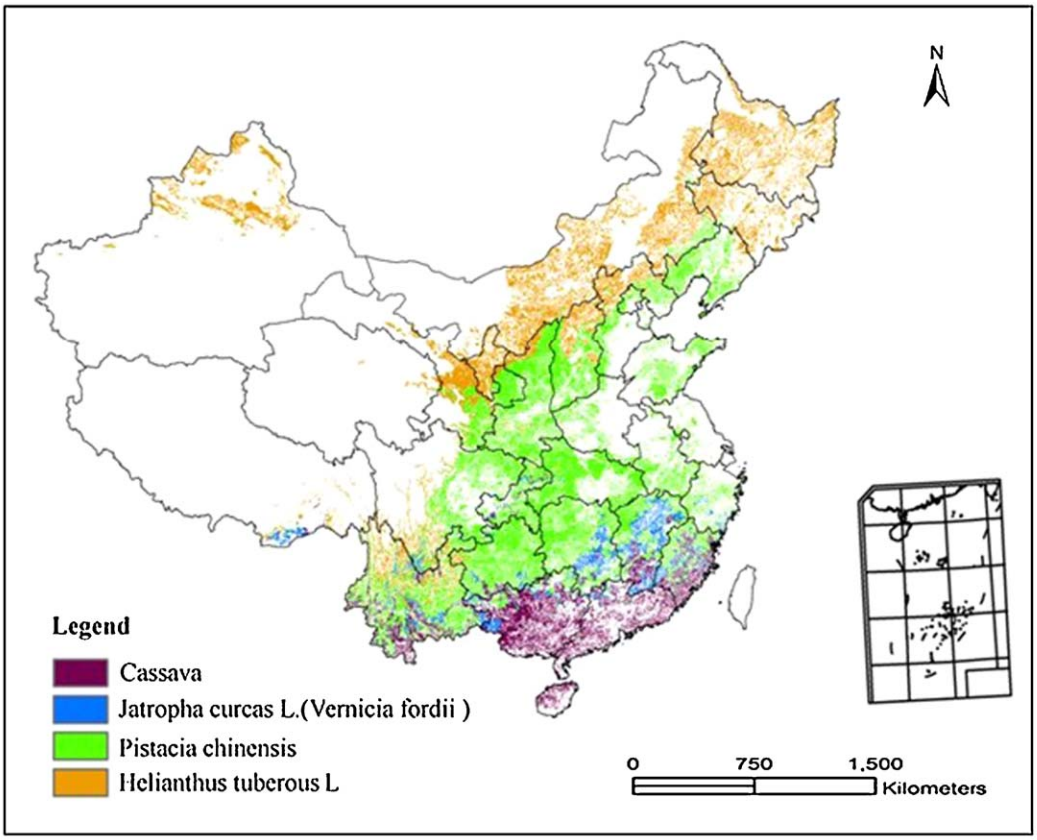


Fig. 3. Planting zonation map of major energy plants in China.

The results have indicated that the total area of marginal land suitable for the development of energy plants on a large scale in recent years, is about 43.75 million ha (6.5 billion mu), and the output of bio-fuel is 133.85 million tons accordingly. If 10% of this marginal land was exploited for planting the energy plants, the output of bio-fuel would be 13.39 million tons.

4. Conclusion

Bioenergy development on the marginal lands has multiple benefits, such as mitigating energy crisis, and reducing greenhouse gas emission. Based on a reasonable definition, accurate and new data resources and multi-factor analysis method, following results have been achieved:

(1) Total area of marginal land suitable for energy plants was estimated up to 130.34 million ha., including forest land (shrub land and open forest land, 50.35%), grassland (45.66%), alkaline land (1.91%) and shoal/bottomland (1.67%). Considering eco-environmental effects of development of energy plants on a large scale, together with natural habits of 5 major species of energy plants, total area of marginal land exploitable for development of energy plants on a large scale in recent years, is about 43.75 million ha.
(2) Five species of energy plants, including H. tuberous L., P. chinensis, J. curcas L., Cassava and V. fordii have been planted in many experimental areas in China and have great potential for bio-fuel development. Based on a combined planting zonation strategy, the area of marginal land suitable for H. tuberous L., P. chinensis, J. curcas L., Cassava are 17.62, 22.94, 3.02 and 0.17 million ha, respectively. The planting zone of V. fordii is similar to that of J. curcas L., however the yield of V. fordii is much lower than the latter [20,22].
(3) The potential output of bio-fuel is approximately 133.85 million tons developed from the 43.75 million ha marginal land. If 10% of this marginal land is exploited for growing the energy plants, the output of bio-fuel will be 13.39 million tons. Therefore, the objective of the national mid- and long-term planning of renewable energy development (bio-fuel developed from non-food plants is expected to be 12 million tons by 2020) will come true.

Development of energy plants on the marginal land on a large scale is a task full of challenges [24,25]. To achieve a win-win result, its ecological and environmental effects together with social and economic benefits should be analyzed and discussed in the subsequent researches.

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